

**SILICON MICROMECHANICS
WITH APPLICATIONS IN OPTICAL
SCANNING AND SENSING SYSTEMS**

by

Kari Gustafsson



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ABSTRACT

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A theoretical vibration analysis of micromechanical cantilever beams showed that, the influence of surface energy effects will only be of significance when the beam thickness approaches atomic dimensions. Experiments indicated that classical continuum mechanics can be applied to designs of sub-micrometer thickness. Analysis of field-assisted glass to silicon bond seals showed that, thermal and residual stresses can greatly reduce the mechanical strength of the bond seal, especially between bulk glass bonded to silicon microstructures. A machinable ceramic was field-assisted bonded to silicon and metals. Results indicated that a bond mechanism similar to those observed in field-assisted glass to metal bonding is present. Fundamental properties of different optical scanning techniques were reviewed. This study showed that most techniques have a limited performance. High-inertia techniques will continue to dominate, but micromechanical scanning devices will have an important impact on present and future optical scanner design.

The design concept of a micromechanical mirror for light scanning seems very promising. The angular velocity obtained is probably the fastest light scanning reported. Experimentally the mirror performed as expected from theory. Three novel fiberoptic devices, incorporating the micromechanical scanning mirror were fabricated; a fiberoptic switch, a four-channel fiberoptic multiplexer and a fiberoptic voltmeter. Silicon micromechanics was also utilized in the fabrication of a fiberoptic pressure sensor in silicon based on fluorescence decay modulation. Each fabricated micromechanical device was analyzed, both theoretically and experimentally.

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To my beloved Elisabeth

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THE THESIS COMPRISES THE FOLLOWING PAPERS:

1. **Vibration analysis of micromechanical elements**
B. Hök and K. Gustafsson
Sensors and Actuators, 8 (1985) 235-243
2. **Strength evaluation of field assisted bond joints and joint systems in glass-silicon microstructures**
S. Johansson, K. Gustafsson and J.-Å. Schweitz
submitted to Sensors and Materials
3. **Field-assisted bonding of a machinable ceramic to silicon and metals**
K. Gustafsson, S. Johansson, B. Hök and T. Murray
submitted to Sensors and Materials
4. **Light scanning techniques- a critical review**
K. Gustafsson and B. Hök
Int. J. of Optoelectronics (in print)
5. **A batch-processed optical scanner**
K. Gustafsson and B. Hök
Proc. 12th Nordic Semiconductor Meeting, Jevnaker, Norway, June 8-11 (1986) 282-285
6. **A silicon light modulator**
K. Gustafsson and B. Hök
J. of Physics E: Sci Instr. 21 (1988) 680-685
7. **Fiberoptic switching and multiplexing with a micromechanical scanning mirror**
K. Gustafsson and B. Hök
4th Int. Conf. on Solid-State Sensors and Actuators (Transducers '87), Tokyo, Japan, June 2-5 (1987) 212-215

8. **A four-channel fiberoptic multiplexer using a silicon scanning mirror**
K. Gustafsson and B. Hök
submitted to Electronics Letters
9. **A novel fiberoptic voltmeter**
K. Gustafsson and B. Hök
Int. J. of Optoelectronics (in print)
10. **A fiberoptic pressure sensor in silicon based on fluorescence decay**
K. Gustafsson, L. Jonsson, B. Hök, C. Ovrén
submitted to Sensors and Actuators

8

ABSTRACT

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The design concept of a micromechanical mirror for light scanning seems very promising. The angular velocity obtained is probably the fastest light scanning reported. Experimentally the mirror performed as expected from theory. Three novel fiberoptic devices, incorporating the micromechanical scanning mirror were fabricated; a fiberoptic switch, a four-channel fiberoptic multiplexer and a fiber-optic voltmeter. Silicon micromechanics was also utilized in the fabrication of a fiberoptic pressure sensor in silicon based on fluorescence decay modulation. Each fabricated micromechanical device was analyzed, both theoretically and experimentally.

keywords: silicon micromechanics, field-assisted bonding, optical scanner, fiber-optic sensor, fiberoptic actuator, fiberoptic multiplexing



PREFACE

It is with great satisfaction that the work on this thesis finally comes to an end. Not only has it been a time full of challenges, but has also given me the opportunity to gain a deeper insight in the fascinating world of physics, for which I am very grateful.

I would especially like to express my sincere gratitude to Adj. Prof. Bertil Hök, who persuaded me to enter the research field of micromechanics and who continuously supported and encouraged me through the different phases of this work with unforgettable enthusiasm and a deep knowledge. I would also like to express my thanks to late Prof. Per-Arne Tove for interesting discussions.

The support and understanding of my fiancée Elisabeth during all hours of the day will always be remembered. Without her encouragement, much of this work would still remain unfinished at this point of time. I also greatly appreciate all the stimulating "around the clock" scientific discussions with my friends Bengt, Olle, Tomas, Erik, Stefan, Björn and Johan. I am greatly indebted to my family and friends for the understanding they have shown throughout this work, even during the midsummer celebrations.

I am also very grateful for the stimulating co-operation with the Fiberoptic Sensor Group of ABB corporate research in Västerås, especially to Lars Jonsson, Doc. Christer Ovrén and Eva Gustafsson, and for their invaluable contributions to this thesis.

Many thanks to all my colleagues at the Electronics Department for creating a stimulating and friendly atmosphere. I would particularly like to thank my co-workers Lars Tenerz, Jonas Tirén, Ylva Lindén and Ulf Lindberg who have been committed and engaged in parts of my work. I wish to thank Doc. Lars Ejdesjö and Doc. Wolfgang Seibt for valuable discussions. Thanks are also due to Lars Carlstrand and Björn Kuzawa for creating a well functioning micromechanics laboratory.

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Special thanks to photographer Teddy Thörlund for producing and creating superb photographic work, even with very little notice. I also wish to express my appreciation to Janet Mason-Jarvis for helpful proof-reading of this summary.

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Uppsala, August 3rd, 1988

Kari Gustafsson
Kari Gustafsson

SUMMARY OF THESIS

INTRODUCTION

Silicon has revolutionized the world during the last twenty years, and today a majority of electronic components and systems are exploiting silicon's electrical properties. Highly advanced silicon processing and materials technology has also been developed. However, during the last ten years a new technology has evolved from silicon integrated circuit technology called silicon micromechanics. This technology exploits the excellent mechanical properties of silicon to fabricate mechanical devices almost as small as microelectronic ones, utilizing to great extent the same fabrication techniques as in traditional integrated circuit fabrication¹.

Three-dimensional structures in almost every conceivable shape such as thin membranes, bridges, cantilever beams, needles, holes, pyramids, walls e.t.c. can be fabricated with silicon micromechanics²⁻³. Since silicon micromechanics uses microelectronic fabrication, these micromechanical devices can be integrated with microelectronics on the same chip, as well as be fabricated inexpensively in a batch process. Though silicon micromechanics has been applied mostly to the fabrication of pressure sensors and to a lesser extent actuators, many other type of sensors are evolving⁴⁻⁵.

The work in this thesis has followed two major lines. One is the analysis of micromechanical elements and systems and different light scanning techniques. The other is the design and fabrication of micromechanical elements and devices applied in the field of fiberoptics.

This chapter presents a summary of the work performed and an overview of the important results presented in the papers comprising this thesis. The outline of this summary will be in accordance with the two major lines of the thesis as described, starting with the analysis part (papers #1 - #4) and concluding with the application oriented part (papers #5 - #10).

ANALYSIS

Silicon micromechanics covers a broad range of processing techniques some of which are unique to the fabrication of sensors and actuators. An insight into the possibilities and limitations of these specific fabrication techniques and their consequences is therefore, valuable. Further, utilizing silicon micromechanics miniaturized mechanical devices with dimensions in the μm range and even smaller is today a reality. The importance of scaling effects should therefore be well recognized by designers of sensors and actuators. Papers #1 - #3 are related to matters of the kind discussed here.

Silicon micromechanics and "micromechanics" in a broader sense, has many potential applications. One is in light scanning devices. In paper #4 different light scanning techniques are analyzed, and the impact of micromechanics on optical scanner design is investigated.

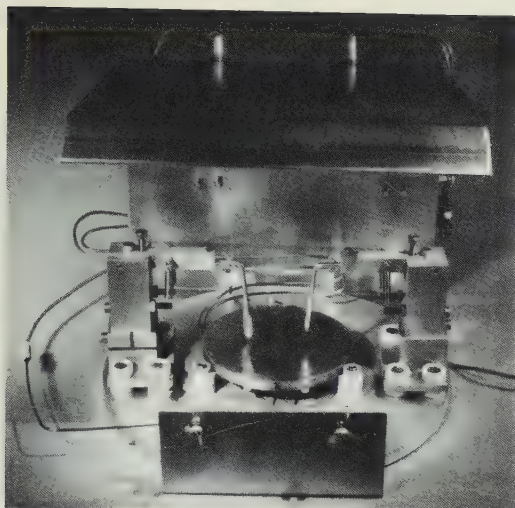
Vibrational analysis of micromechanical elements

In paper #1, the vibrational behaviour of micromechanical elements was studied both theoretically and experimentally. The question tried to be answered is: When micromechanical devices are miniaturized, are the classical continuum models sufficient to describe their behaviour or do they have to be modified? The theoretical analysis was restricted to the behaviour of cantilever beams and the influence of the surface energy effects on the mechanical resonance frequency. Results from our theory show that surface energy effects will only be of significance when the cantilever beam thickness approaches atomic dimensions. Experimental results from resonance frequency measurements that were performed on cantilever beams of silicon, gallium arsenide, glass, aluminum and organic polymers (Kapton[®] and PVF₂(Kynar[®])) and with varying physical dimensions, indicated that the equations describing resonance frequency in classical continuum mechanics can be applied to all practical designs of sub-micrometer thickness using state-of-the-art-technology.

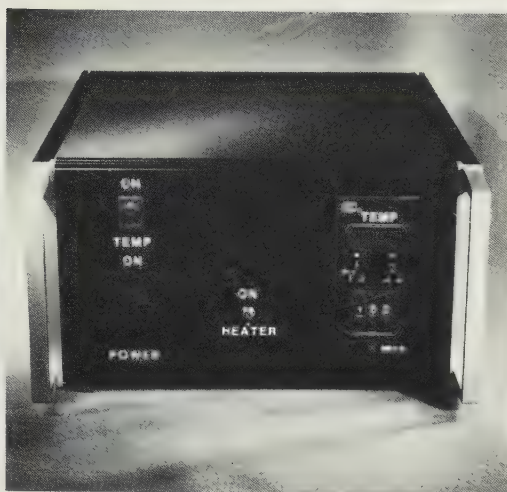
Measurements of the intrinsic quality factor, Q , for different materials were also made. A wide spread in Q values was observed, covering more than three orders of magnitude. Surprisingly it was found that cantilever beams of GaAs-Al_xGa_{1-x}As had a higher intrinsic Q value than silicon.

Analysis of field-assisted bond seals in microstructures

Paper #2 and paper #3 are focused on a sealing method called field-assisted bonding (FAB). FAB is a sealing technique which has been widely used in micromechanical sensor fabrication to bond silicon to glass or silicon to silicon with an interlayer of glass⁶. A bonding apparatus was constructed for FAB and is depicted in Fig.1. There



(a)

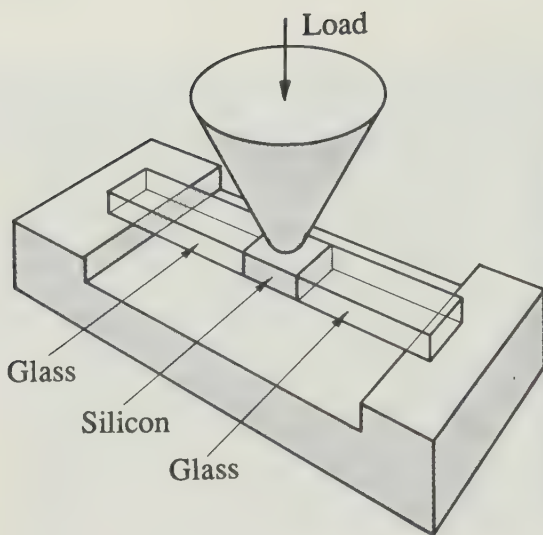


(b)

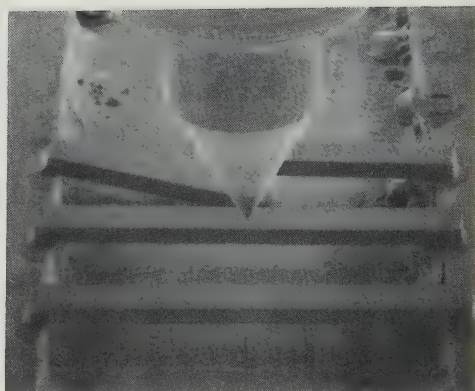
Fig.1 Photographs of the constructed bonding apparatus used in bonding silicon and a ceramic to various materials. (a) The main unit where bonding is performed and (b) the electronic unit controlling the operation of the main unit. Bonding at temperatures as high as 750 °C has been performed with this apparatus.

are certain requirements concerning the materials to be bonded and the process parameters. In brief, the process for bonding silicon to glass is as follows. Glass and silicon are heated in contact with each other, typically to 400 °C, and a voltage (50-1000 V) is applied over the materials, so that silicon is positive with respect to the glass. Almost immediately, large electric fields ($\sim$ MV/cm) build up over the silicon-glass interface, and these fields will pull the two materials together and form a bond. The formation of the FAB-seal is completed after a few minutes.

In paper #2 the mechanical strength, and factors affecting it, was investigated for FAB of silicon to glass and silicon to silicon using a glass interlayer. Bulk silicon, with or without etched-out microstructures, was bonded to both bulk glass and to thin glass interlayers, and the mechanical strength of the seals was tested. The ratio of the bonded area of a microstructure in silicon to the total area was also varied for the different bonding conditions described. One of the methods of measuring the strength of FAB-seals is shown in Fig.2, where three-point bend testing of FAB seals in a glass-silicon-glass beam in situ in a scanning electron microscope (SEM) is performed. The important results from this investigation is that, when bonding spaced but interconnected silicon microstructures to glass, thermal and residual stresses are ma-



(a)



(b)

Fig.2. (a) Geometry of tested bond specimen and bond test arrangement used in-situ in a scanning electron microscope (SEM) as shown in (b).

for strength reducing factors. To successfully bond microstructures in silicon to glass, either a ratio between bonded area to total area exceeding 1:100 is required when using bulk glass, or bonding to a thin glass layer is required. Furthermore, it was found that the elimination of dust particles can even further improve the mechanical strength of a silicon-glass seal. Three-point bend testing of FAB-seals resulted in much higher fracture limits than previously published: 120-250 MPa.

FAB of a machinable ceramic to silicon and to certain metals is presented in paper #3. Bonding parameters, -mechanism and -strength were investigated and an STEM/EDS analysis of the silicon ceramic seal was performed. The experiments showed that a critical amount of charge was required for strong silicon-ceramic bonds, as seen in Fig.3. The results also indicate that a bond mechanism similar to those observed in FAB of glass to metal and β -alumina to metal is involved. An application of the technique for bonding a machined microfluid connector made of this ceramic to a silicon substrate was demonstrated. This application example is shown in Fig.4.

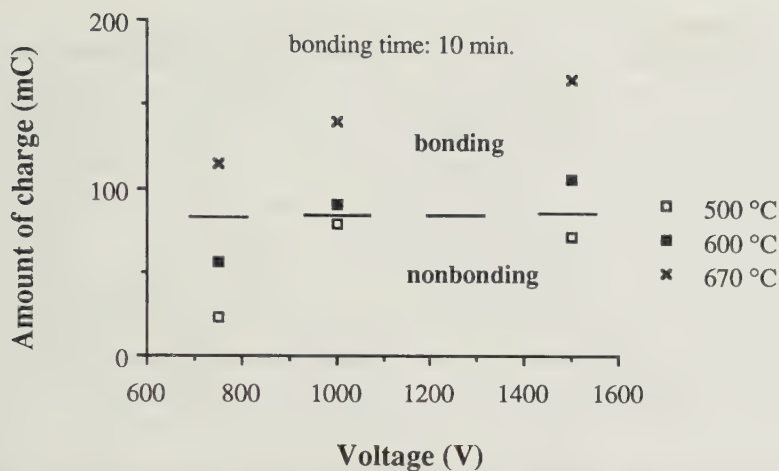
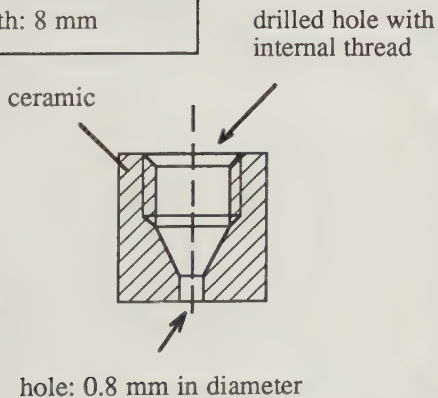
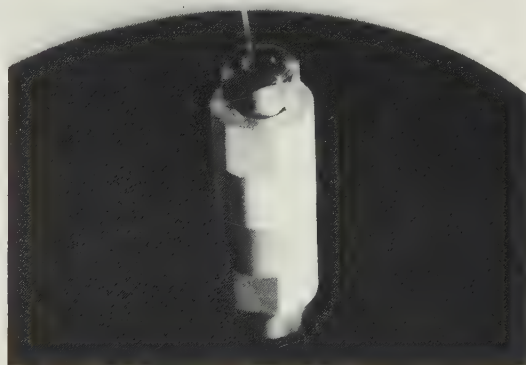


Fig.3. Amount of charge flow during bonding of silicon to ceramic specimens versus bonding voltage. Each point in the diagram represents one bonded specimen.

Geometrical data
outer diameter: 7 mm
length: 8 mm



(a)



(b)

Fig.4.(a) Schematic drawing of the cross-section of the machined ceramic connector that was bonded to a silicon wafer. (b) A photograph of the machined connector bonded to a silicon wafer using the bond technique described in paper #3. Silica tubing 0.5 mm in diameter protrudes at the top of the nut, which is screwed into the ceramic connector.

Light scanning techniques - a critical review

In paper #4, fundamental properties of different scanning techniques were reviewed. The impact of some recent advances in materials science and technology are discussed together with speculations about future development of this branch of technology. The results of this study show that none of the techniques described is presently best suited for a majority of applications, and even the best choice for certain applications has a limited performance.

Motor driven mirrors and the d'Arsonval type of galvanometers are techniques that will dominate light scanning for several years to come. High volume production of simple, mechanical devices will always remain competitive, especially if modern technology is incorporated when appropriate. The micromechanical quartz mirror galvanometer is one example of such an implementation of modern technology.

It is also clear that recent breakthroughs in micromechanics will have an important impact on present and future optical scanner design. The borderline between high-inertia and low-inertia scanning devices will probably be partly erased. The continuing development of electrostatic micromotors will be extremely important.

The field of application of optical scanners is likely to be widened as the performance is increased. Optical memories, projection displays, laser writers and "active optics" for use in fiberoptic communication, cameras, microscopes, solar cells e.t.c. are some possible areas of application. A difficulty is, of course, that most of these areas imply new and yet unproven technology. This means that there is a substantial threshold that must be passed before such products are in general use.

MICROMECHANICAL APPLICATIONS

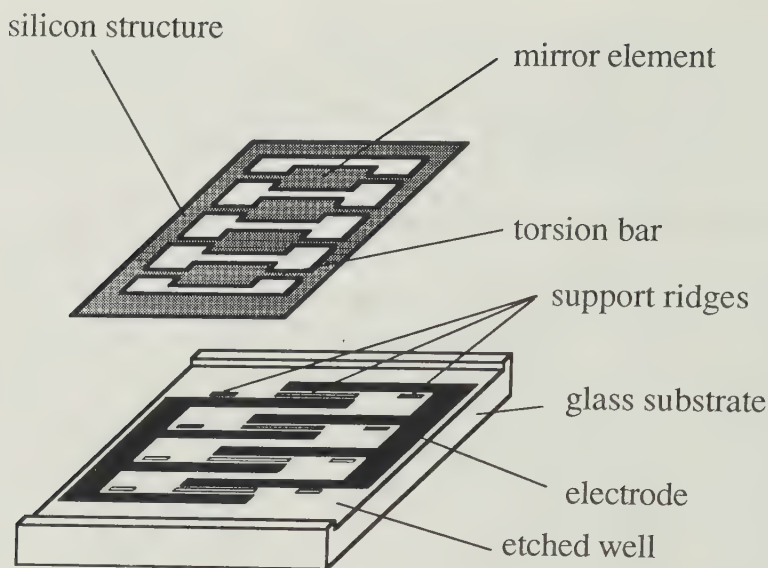
Papers #5 - #9 are related to the design, fabrication and applications of a micro-mechanical optical scanner. The final paper #10 presents a fiberoptic pressure sensor based on fluorescence modulation and fabricated with silicon micromechanics

Design and fabrication of a micromechanical scanning mirror

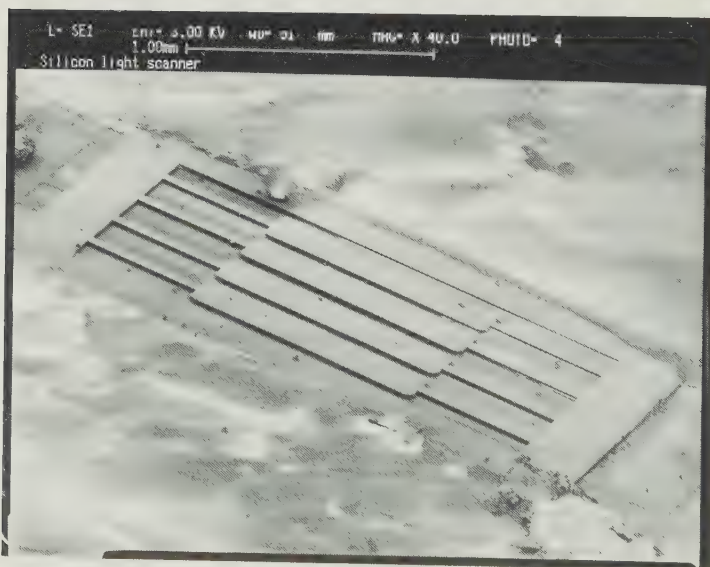
The starting point was a concept of a micromechanical scanning mirror for the scanning of light, based on the ideas that Petersen had earlier described when presenting a silicon torsional scanning mirror⁷ in a pioneering work in 1980. However, this concept was different in design from several aspects. While Petersen's design consisted of one electrostatically activated mirror with torsion suspension, measuring 2 x 2 mm and 0.13 mm in thickness, our design was based on an array of long and narrow mirror elements (0.2 x 1 x 0.007 mm), torsion suspended and individually electrostatically activated. Several advantages may result from this design. For example, using several small mirrors with an active mirror area equivalent to just one mirror, faster modulation of light can be achieved than with just one mirror because of the extremely low moment of inertia of each mirror element. Furthermore, the possibility of electrically controlling the deflection of the mirrors (individually) allows greater operating flexibility (e.g. the mirrors can be operated above resonance in a controlled fashion) and opens up new applications. The proposed concept aimed at applications in the field of fiberoptic measurement systems, at that time an activity of ABB corporate research, who also supported this preliminary work.

The objective of paper #5 was to study the feasibility of the proposed concept by designing and fabricating the first prototype micromechanical scanning mirror in a batch process. A schematic drawing of the design is shown in Fig. 5a, and a photograph of a fabricated scanner device is depicted in Fig. 5b. The scanning mirror consists of an etched silicon structure, containing an array of four torsion suspended mirror elements in silicon, and a glass substrate with an etched well on which to interlaced electrode patterns have been deposited and support ridges have been formed. The entire silicon structure is 7 μm thick and the separation between the mirror elements and the underlying electrode pattern is about 10 μm . Each mirror element is 200 μm wide and 1 000 μm long, and the torsion bars are 50 μm wide and 500 μm long.

Operation of the scanning mirror is obtained upon applying a voltage between the silicon structure and one of the electrode patterns. This results in a torsional movement of the mirror elements, due to the electrostatic force acting on each mirror element.



(a)



(b)

Fig.5.(a) Schematic drawing of the designed micromechanical scanning mirror, showing silicon structure containing four torsion suspended silicon mirrors and glass substrate with support ridges and electrodes. (b) A photograph of the fabricated micromechanical scanning mirror. The white marker in the top section of the photograph is equivalent to 1 mm.

Fabrication of the device followed micromechanical processing techniques. For the silicon structure the starting material was a n^+ -substrate with a $7\text{ }\mu\text{m}$ thick n -type epilayer. The mirror elements were first defined in an anisotropic wet etchant (KOH). In a final step, the substrate was removed with an isotropic electrochemical wet etch ($\text{HF}+\text{H}_2\text{O}$) and the $7\text{ }\mu\text{m}$ thick silicon structure containing individual mirror elements was freed. To fabricate the glass substrate, isotropic wet etching ($\text{HF}+\text{NH}_4\text{F}$) was used to form the well with the support ridges in a glass plate. After the electrode metallization was deposited through evaporation of aluminum and the electrode patterned was etched out, the glass substrates were cut from the glass plate. In a last crucial step, the processed silicon structure was positioned and glued on top of the etched glass substrate and wires to the electrodes and the silicon structure were attached. Experiments on the prototype device verified the light deflecting properties of the scanning mirror. A mirror deflection of 0.10 degrees with an applied voltage of 150 V and a mechanical resonance frequency of the mirrors of 38 kHz with a Q value of about 11 was experimentally obtained. Further, according to theory the angular deflection below the resonance was expected to show a square law dependence on the applied voltage. A subsequent experiment confirmed this was the case. Hence, the new design concept of deflecting light with an array of micromechanical scanning mirrors in silicon seemed feasible.

In paper #6 a more thorough theoretical and experimental treatment of the micromechanical scanning mirror structure was undertaken to investigate the full potential of silicon micromechanics applied to light scanning devices. A comparison of the modelled and the experimentally measured characteristics of the scanning mirror was presented and potential applications were also given.

The results of this work were that the concept of using small, light-weight, high-precision mirror elements in silicon, fabricated with silicon micromechanics and using electrostatic activation to deflect a light beam is promising. For example, the angular velocity obtained, 7×10^5 degrees/sec, probably represents the fastest light scanning yet reported. The prototype scanning mirror performed as expected from theory, and an improved mirror structure would probably result in a performance that is even more acceptable in all respects. Experimentally, deflections of 0.46 degrees at 100 V applied voltage (below resonance), a threshold voltage of 185 V (the voltage over which the mirrors spontaneously rotate the remaining distance to the bottom electrode) and a mechanical resonance of 40 kHz ($Q \sim 8$) was measured. Deflections of $2\text{--}3$ degrees were observed when operating the scanner at resonance

Applications of the micromechanical scanning mirror

Papers #7 - #9 are all related to applications of the micromechanical scanning mirror presented in the two previous papers (#5,#6). In a first application the scanning mirror was incorporated in a fiberoptic switch (paper #7). A new class of fiberoptic switches and multiplexers were thus introduced with this concept. The same basic concept was used to design and fabricate a four-channel multiplexer (paper #8), which will be described in greater detail at a later stage of this summary.

A fiberoptic switch

The concept of fiberoptic switching was based on the micromechanical scanning mirror and an optical lens arrangement, which comprised of a microlens and an input and output fiber. By operating the scanning mirror in resonance (40 kHz), light from the input fiber was reflected from the mirror to the output fiber, at an angle determined by the deflection of the mirror elements. Experiments showed that a major portion of the modulated light in the input fiber was switched from one fiber over to the other. Important factors in fiberoptic switching and multiplexing systems such as overall damping and cross talk attenuation and the varying contribution to these factors from this device were also discussed in this paper.

A four-channel fiberoptic multiplexer

In paper #8 a four-channel fiberoptic multiplexer of time division type was presented. The concept was based on deflection of collimated light from an optical fiber using the micromechanical scanning mirror and an optical lens arrangement. The optical lens arrangement was based on the same basic optical principle utilized in the fiberoptic switch. A schematic drawing of the multiplexer is shown in Fig.6. The operation is as follows. Light from the center fiber (#3) is collimated by the graded index (GRIN)-lens before it strikes the active mirror area. The electrostatically deflected mirrors cause the light beam to then be deflected back into the GRIN-lens in a direction determined by the mirror deflection, and consequently, to become focused on a different fiber (#5 in Fig.6). By controlling the mirror deflection with the applied voltage, different fibers can be addressed.

Time division multiplexing with this device was performed with the scanning mirror operating at its mechanical resonance (40 kHz) and applying a sinusoidal voltage of 140 V to the scanning mirror. The measured modulation intensities were symmetrical with respect to changing of fibers (#1 to #5, #2 to #4). Further, the ratio between modulated light to stray light was approximately one in all fibers. The characteristics of the optical lens arrangement were also investigated. Measurements made on an idealized mirror showed that a cross talk attenuation and an insertion loss of -31 dB

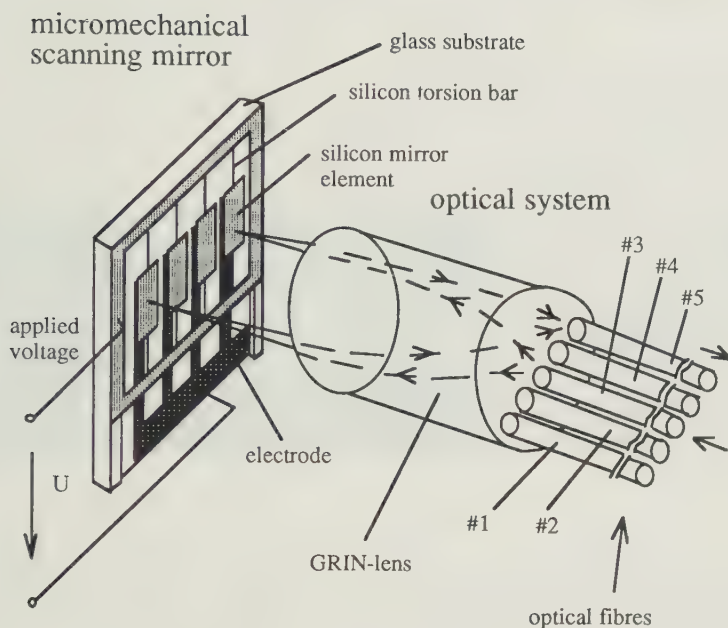
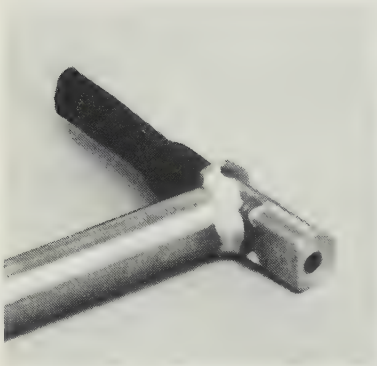
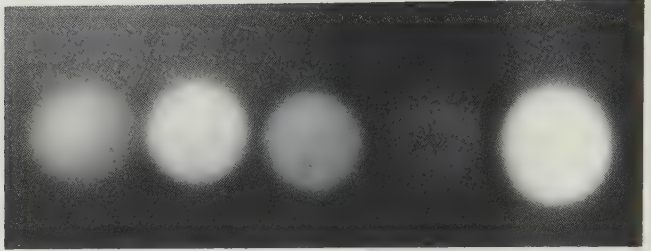


Fig.6. A schematic drawing of the multiplexer and its principle operation (see text for explanation). The objects are not drawn to scale.

and -6 dB, respectively, can be expected with the kind of device presented here. Another important result of this work was also that an array of five fibers connected to a GRIN-lens could be fabricated with conventional techniques. In Fig.7a the optical system is depicted, and in Fig.7b the close and precise arrangement of the the fibers is shown with a photograph of the light emerging from the fiber ends located at the back surface of the lens (the surface where the fibers terminate).



(a)



(b)

Fig.7. (a) A photograph of the optical system. The bevelled metal cylinder in the lower right corner is a steel cylinder housing the GRIN-lens (the dark circular spot is the front surface (the surface facing the mirrors) of the GRIN-lens)). This cylinder is mounted to a fiber holder, which contains the fibers seen in the upper left corner. (b) The light emerging from the five fiber ends entering the lens is shown while guiding light in all five fibers into the optical system and observing the light from the fiberends through the front surface and into the GRIN-lens. Each bright spot corresponds to an illuminated fiber core of $100\ \mu\text{m}$ in diameter. The separation between the fibers is $10\ \mu\text{m}$.

A novel fiberoptic voltmeter

A novel fiberoptic voltmeter was constructed and is presented in paper #9. The voltage sensor is an extrinsic nonpolarimetric and intensity modulated type of fiberoptic sensor. A micromechanical scanning mirror and an optical fiber-GRIN-lens system, of the kind employed in the fiberoptic multiplexer is utilized except that just one central fiber is used, comprises the voltage sensor. Operation is based on optically measuring the electrostatic deflection of the mirror elements induced by the applied voltage. This is accomplished by letting the mirror structure intensity modulate that proportion of the light which is being reflected back into the optical fiber (the proportion is determined by the applied voltage).

The characteristics of the sensor are: high input impedance (equivalent to that of a 1pF capacitor), an ability to perform differential measurements separated from ground potential, measurable voltages ranging from 0 to 120 V (larger values limited

by the threshold voltage of the mirror) and a bandwidth from D.C. to 15 kHz. The voltage sensor has a quadratic transfer function (modulated light intensity as a function of applied voltage).

The theory for the sensor operating as a voltmeter was given. Experimentally, the modulated reflected intensity from the sensor as a function of applied voltage for four different frequencies was measured. The result of this measurement is shown in Fig.8. Further, an input impedance of the sensor equivalent to a capacitor of 1-1.5 pF in parallel with a resistance of about 10^{12} ohm was measured, and a relatively large temperature sensitivity was observed in a simple test that was carried out. Other applications of this voltage sensor, for example in measuring the electric field, were discussed together with further improvements of the voltage measuring concept.

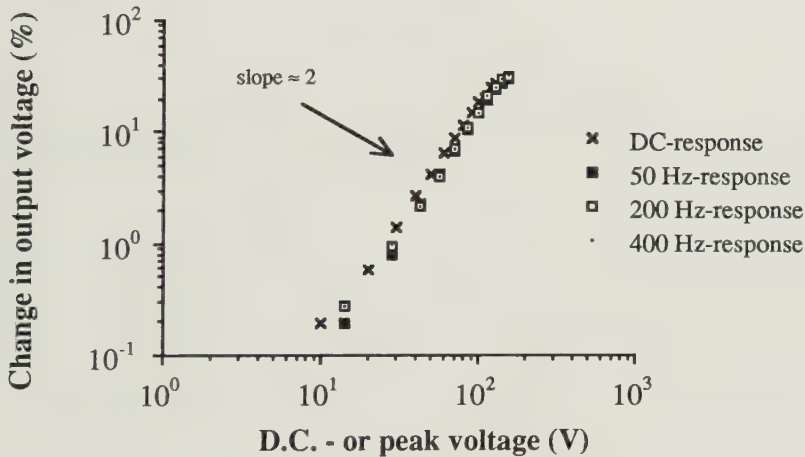


Fig.8. Measured relative change in sensor output voltage with applied voltage at D.C., 50, 200 and 400 Hz. The output voltage in the diagram is proportional to the reflected light intensity in the fiber.

A fiberoptic pressure sensor in silicon

In the final paper (#10) a multimode fiberoptic pressure sensor based on fluorescence decay modulation in neodymium-doped glass is presented. Silicon micromechanics is used to fabricate a pressure diaphragm and a sensor structure.

The design of the sensor is illustrated in the schematic diagram in Fig.9. Non coherent light is guided in one multimode fiber to the sensor element of the pressure

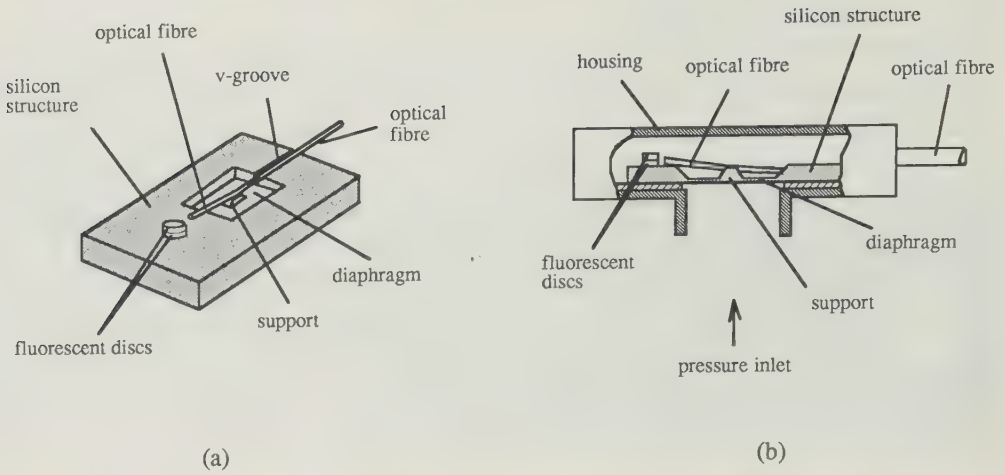


Fig.9. (a) View of sensor element of pressure sensor. (b) Schematic cross section of pressure sensor.

sensor. In addition to the optical fiber, the sensor element comprises a silicon structure and two neodymium-doped glass discs. The fluorescence lifetime of neodymium in the two fluorescent discs is different. A square diaphragm, a central support ridge and a v-groove are formed in the silicon structure. The optical fiber is aligned in the v-groove and continues across the diaphragm to the two glass discs. When pressure is applied to the pressure inlet, the silicon diaphragm will deflect. So too will the optical fiber, resulting in a nearly vertical movement of the fiber tip (because of the support ridge in the middle of the diaphragm) from one fluorescent disc to the other. The fluorescence signal in the fiber will thus have a varying contribution from the two fluorescent discs, depending on the pressure. Phase sensitive detection schemes can then be used to detect the pressure dependent fluorescence re-emitted back into the fiber.

Silicon micromechanics was used to fabricate the sensor structure. An anisotropic etch (KOH) was used to etch a diaphragm with a v-groove and a support ridge with well defined geometrical dimensions. The diaphragms fabricated and used in this prototype sensor had a thickness of about 40 to 80 μm and a diaphragm length of 2 to 4 mm. A photograph of an early sensor element prototype is shown in Fig.10.

A theoretical analysis of the sensor characteristics was performed, indicating that the pressure sensor will have a dynamic range of 50 dB over 1 kHz bandwidth. The maximum allowed pressure with these particular dimensions of the silicon diaphragm

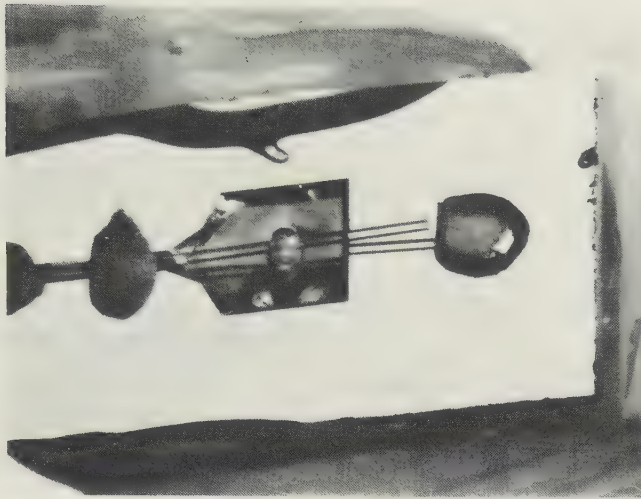


Fig.10. Photograph of an an early fabricated and assembled sensor element. The thickness of the silicon diaphragm is here 75 μm .

is about 5 bar. The sensor response to an applied static pressure was measured, and is shown in Fig.11. The response is clearly very linear over the entire pressure range (0-2 bar), as expected from the theoretical analysis.

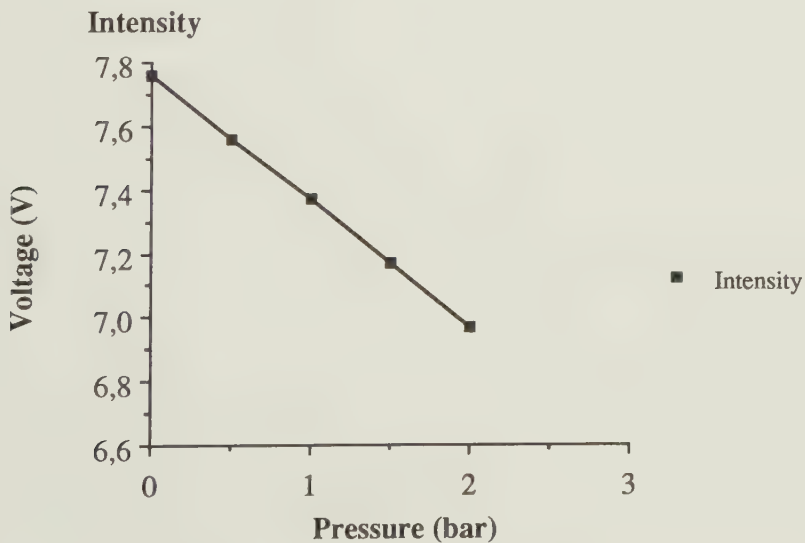


Fig.11. Measured static pressure response. Reflected intensity in the fiber, which is proportional to the detector voltage, as a function of applied voltage

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